**Introduction**

Open CSR Example 1, <https://beta.sirepo.com/elegant#/source/WDvfGt6G> and go to ‘Lattice’. You should see a linac section followed by a compression chicane, constructed of four dipoles, this is followed by a FODO cell with four quadrupoles. For this exercise we will look at the effects of CSR on a bunch that has been compressed in the chicane and try examining some of the options for how elegant handles the modeling of CSR. Initially CSR is turned off in each of the four dipoles. We will primarily look at four different diagnostics in the Visualization tab:

* run\_setup.output: The longitudinal phase space of the bunch at the very end of the beam line.
* hist\_chicane: A histogram taken at the entrance to the chicane.
* hist\_chicane\_end: A histogram taken at the exit of the chicane.
* hist\_final: A histogram at the very end of the beam line.

1. Before the simulation can be run you will need to calculate the optimal accelerating phase in the linac to fully compress the bunch in the chicane. The compression ratio is given by:

Where h is the linear chirp and R56 comes from the R-matrix for the lattice.

To calculate the linear chirp you will use:



Where k is the wavenumber of the linac cavities, Vtot is the linac voltage contribution from all cavities, E0 is the initial energy of the beam in eV, and is the accelerating phase.

* 1. There are 86 cells in each cavity section and 4 total cavity sections in the beam line. You can find the voltage for a single cell by finding the RFCA element ‘R1’ and checking the number for voltage. Use this to calculate the total accelerating voltage of the linac.
  2. Look again at the RFCA element ‘R1’ to find the cavity frequency. Use this to calculate k.
  3. Go to the source tab and look at the value of ‘Central momentum of the beamline’ this is the initial momentum of the bunch at the linac entrance. Use this calculate the energy E0.
  4. Go visualization and run the simulation. Look at matrix\_output.SDDS\_output and plot *R56 vs s* to find R56 at the end of the chicane.
  5. Now that you have all the components calculate the optimal phase to maximize the compression ratio C. When you have this number verify it with the instructor. Then in lattice got to RPN variables (under Beamline Elements) and put in the value for ‘PHASE’

1. Go to ‘Visualization’ and run the simulation.
   1. Look at plots of *tFrequency vs t* in hist\_chicane and hist\_chicane\_end. What has happened to the longitudinal distribution of the bunch?
   2. Now change the histograms to plot *deltaFrequency vs delta*. Do the distributions look different at the beginning and end of the chicane?
   3. In run\_setup.output make sure *p vs t* is plotted. Save a picture of the longitudinal phase space.
2. Let’s turn on CSR in the dipoles and see what happens. Go to ‘Control’ and find the ‘alter\_elements’ command with ‘item = CSR, name = BEND?’. Change ‘Value’ from 0 to 1 and save changes. Go back and rerun the simulation.
   1. How does the longitudinal phase space in run\_setup.output look different from the picture you saved with CSR off?
   2. Look at the histograms of deltaFrequency vs delta at the start and end of the chicane. Why have they changed?
   3. Before we move on lets plot *enx vs s* in run\_setup.sigma (if it is not already shown). Use this plot to record *enx*, the normalized x-emittance, at the end of beam line.
3. Next let’s try adjusting how elegant is modeling the CSR. Right now we are using the ‘Steady State’ CSR model. Now let’s change the model. Go to control and find the ‘alter\_elements’ command that says ‘item = STEADY\_STATE, name = BEND?’. Change ‘Value’ from 1 to 0 and save changes. Now when we run the simulation elegant will use a more sophisticated calculation of CSR that includes transient effects.
   1. Based on what you’ve learned what do you think will happen to the emittance at the end of the beam line? Will it be higher, lower, or unchanged?
   2. Now rerun the simulation. Look at *enx* at the end of the beam line again. What happened? Can you explain your observation?
4. Now let’s turn on one more option in elegant’s CSR routines. Currently the electrons only experience CSR while they are in a dipole. However, while electrons won’t produce radiation outside the dipole, any radiation they produced in an upstream dipole could continue to propagate with the electrons out into a drift space. Let’s turn on ‘csrdrifts’ to allow this effect. Go to ‘Control’ and find the ‘alter\_elements’ command with ‘item = CSR, name = D\_FODO’ and change ‘value’ from 0 to 1. Now rerun the simulation.
   1. Now look at the hist\_chicane\_end and hist\_final plots and plot *deltaFrequency vs delta* in each one. Are they different? Why is this?
   2. Look *at tFrequency vs t* in hist\_chicane\_end and hist\_final. Are they different? Why or why not?
   3. Look at *enx*, what is the value of *enx*? Has it changed? Why would this be?
5. Go to CSR example 2, <https://beta.sirepo.com/elegant#/source/k70xC9OK>. This simulation has been set up to scan over the accelerating phase, with the start and end points centered around the optimal phase you previously found. Go and run the simulation. Sirepo/elegant will produce a series of plots, one for each step. In the run\_setup.output plot pane make sure the *p vs t* is being plotted then hit the back button and then play.
   1. Describe what you are seeing.